

# Distributed Data Acquisition System for Pachmarhi Array of Čerenkov Telescopes

**P. N. Bhat, B. S. Acharya, V. R. Chitnis, A. I. D’Souza, P. J. Francis, K. S. Gothe, S. R. Joshi, P. Majumdar, B. K. Nagesh, M. S. Pose, P. N. Purohit, M. A. Rahman, K. K. Rao, S. K. Rao, S. K. Sharma, B. B. Singh, A. J. Stanislaus, P. V. Sudershanan, S. S. Upadhyaya, B. L. V. Murthy, and P. R. Vishwanath**

Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India

**Abstract.** Pachmarhi Array of Čerenkov Telescopes (PACT) consists of a  $5 \times 5$  array of Čerenkov telescopes deployed over an area of  $100\text{ m} \times 80\text{ m}$ , in the form of a rectangular matrix. The experiment is based on atmospheric Čerenkov technique using wavefront sampling technique. Each telescope consists of 7 parabolic mirrors mounted para-axially on an equatorial mount. At the focus of each mirror a fast phototube is mounted. In this experiment a large number of parameters have to be measured and recorded from each of the 175 phototubes in the shortest possible time. Further, the counting rates from each phototube as well as the analog sum of the 7 phototubes from each telescope (royal sum) need to be monitored at regular intervals during the run. In view of the complexity of the system, the entire array is divided into four smaller sectors each of which is handled by an independent field signal processing centre (FSPC) housed in a control room that collects, processes and records information from nearby six telescopes that belong to that sector. The distributed data acquisition system (DDAS) developed for the purpose consists of stand-alone sector data acquisition system (SDAS) in each of the four FSPC’s and a master data acquisition system (MDAS). MDAS running in the master signal processing centre (MSPC) records data from each of the 25 telescopes. The data acquisition and monitoring PCs (SDAS and MDAS) are networked through LAN. The entire real time software for DDAS is developed in C under *linux* environment. Most of the hardware in DDAS are designed and fabricated in-house. The design features and the performance of the entire system along with some other auxiliary systems to facilitate the entire observations will be presented.

## 1 Introduction

Pachmarhi Array of Čerenkov Telescopes is a ground based atmospheric Čerenkov experiment designed to study VHE

*Correspondence to:* P. N. Bhat (pnbhat@tifr.res.in)

$\gamma$ -ray emission from astronomical sources. This experiment is based on wavefront sampling technique and consists of an array of 25 telescopes spread over an area of  $80\text{ m} \times 100\text{ m}$ , at Pachmarhi in Central India. Spacing between neighbouring telescopes is  $20\text{ m}$  in E-W direction and  $25\text{ m}$  in N-S direction. Each telescope consists of 7 para-axially mounted parabolic mirrors of diameter  $0.9\text{ m}$  with a fast phototube at the focus of each mirror. Each telescope is equatorially mounted and its movement is remotely controlled and monitored in the control room. Some of the design details of this experiment are given by Chitnis et al., 2001. Using the array, arrival time of Čerenkov shower front and Čerenkov photon density are measured at various locations in the Čerenkov pool generated by air showers. In this paper we discuss the design of data acquisition system used in this experiment.

## 2 Experimental setup

Pachmarhi array is divided into four subgroups or sectors of six telescopes each (see Figure 1). Each sector can be operated as an independent unit. At the centre of each sector there is a station housing field signal processing centre (FSPC). Pulses from phototubes are brought to the respective centre through low attenuation RG213 cables of length  $\sim 40\text{ m}$  each. Since the array is split into the sectors, length of pulse cable is reduced thereby minimizing the distortion and attenuation of weak pulses from phototubes during their transmission through cables. In these type of experiments, it is necessary to preserve the shape and size of the Čerenkov pulse as much as possible to improve the angular as well as energy resolution of the experiment. Pulses from individual mirrors are processed and the informations regarding pulse height and arrival time of shower front at mirrors is recorded by FSPC. At the centre of the array there is a control room which houses master signal processing centre (MSPC). Information relevant to entire array such as arrival time of shower front at individual telescopes, absolute arrival time of the event *etc* are recorded by the MSPC.

Figure 2 shows the experimental setup schematically. High voltages of individual phototubes are controlled through Computerized Automated Rate Adjustment and Monitoring System (CARAMS). Orientation of telescope mounts is controlled by Automated Computerized Telescope Orientation System (ACTOS). Pulses from individual phototubes are brought to the respective FSPC which processes the pulses and generates trigger. On generation of trigger, information is recorded by *Linux* PC. Once a trigger is generated by any of the stations, MSPC in control room records information relevant to entire array. In the following, we discuss details of these subsystems.

### 3 Auxiliary control systems

Auxiliary control systems include systems for phototube high voltage control, orientation of telescopes and a remotely controlled phototube shutter mechanism called APES. Details of these subsystems are given below.

#### 3.1 Computerized Automated Rate Adjustment and Monitoring System (CARAMS)

It is necessary to ensure that the gains of all the phototubes are more or less equal by equalizing their counting rates due to NSB. This is achieved by setting high voltages of individual phototubes such that their count rates are approximately equal. Given the differences in characteristics of individual phototubes as well as differences in reflectivities of mirrors, high voltage requirements differ from one phototube to another. In addition, the counting rates are sensitive to sky brightness, sky clarity, ambient temperature, ambient light pollution *etc*, and hence there is a need to adjust them every night. This process is quite time consuming. Hence CARAMS is designed for adjusting individual rates and monitoring them. This system consists of the microprocessor based 64 channel high voltage divider unit (C.A.E.N. model SY170) which is controlled by CAMAC based controller module (C.A.E.N. model CY117B). High voltage is given to the crate and output voltage from each channel is adjusted using a resistance divider network and a micro-motor. CARAMS is developed for changing the phototube voltages as well as for reading them back using suitable CAMAC commands to the controller module. Rates from phototubes are measured using scaler modules and are available to CARAMS. Counting rates are measured at a few fiducial values encompassing the required counting rate. A quadratic fit is used to define the variation of counting rate as a function of applied high voltage for each phototube. Then the required high voltage is computed using interpolation. The required counting rate is then obtained by a few iterations around the interpolated value. This procedure is fast and efficient. Using CARAMS, counting rates of all 175 phototubes can be adjusted in about 20 minutes.

#### 3.2 Automated Computerized Telescope Orientation System (ACTOS)

During observations, it is necessary to ensure that all telescopes are tracking the putative source accurately. Also the provision for fast movement of telescopes while switching over from source to background observations or from one source to another is needed. Low cost Automated Computerized Telescope Orientation System (ACTOS) is designed to achieve this. All the telescopes are equatorially mounted and each telescope is independently steerable in both E-W and N-S direction within  $\pm 45^\circ$ . The hardware of ACTOS designed in-house for remotely controlling movement of these telescopes consists of a semi-intelligent closed loop feedback system with built-in safety features. The heart of the system is an angular position sensor which is basically a gravity based transducer called clinometer (see Figure 3). The clinometers whose DC outputs are linearly proportional to their offset angles from vertical ( $60\text{ mV/deg}$ ) are used as absolute angle encoders. Two clinometers are used, one to get telescope angle in N-S direction and other for E-W direction. These clinometers are calibrated by aligning telescopes to stars at various angles and measuring clinometer output voltages. Clinometer outputs are given to a low pass filter and an integration type ADC which is readout by a host-PC. The motor controller, an interface between the host-PC and the stepper motor, carries out the task of movement of stepper motors as instructed by the host-PC. Variable slew speeds are used to decelerate the speeding telescope in steps. At present three different speeds are used, *viz.*, fast (70 Hz), slow (30 Hz) and tracking (7.561 Hz). The system can orient to the putative source from an arbitrary initial position with an accuracy of  $\sim (0.003 \pm 0.2)$ . The source pointing is monitored at an accuracy of  $\sim 0.05^\circ$  and corrected in real time. For details on ACTOS refer to Gothe *et al.* (2000)

### 4 Distributed Data Acquisition System (DDAS)

DDAS consists of a Sector Data Acquisition System (SDAS) in four stations and a Master Data Acquisition System (MDAS) in the main control room.

#### 4.1 Sector data acquisition system (SDAS)

SDAS is designed to process the pulses from phototubes, generate a trigger and record the required information locally. Two types of data are recorded by SDAS. On event trigger, event arrival time, arrival time of the Čerenkov shower front and the photon density at individual mirrors are recorded. On monitor trigger, which is variable but periodic, count rates from various mirrors as well as telescope trigger rates are recorded. Block diagram of SDAS is shown in Figure 4. Pulses from phototubes are brought to the station through a low attenuation coaxial cables and given to linear fan-out unit which produces three replica of the input pulse. One set outputs from this module are given to Fan-in-fan-out unit

which adds all the 7 analog pulses from phototubes of a telescope. These analog sums are called Royal Sums. Other set of outputs from fan-out unit is discriminated. One set of discriminator outputs is given to digital delay circuit, output of which form the TDC STOP's. The other set of discriminator outputs goes to CAMAC scalers which measure the count rates. Third set of outputs from fan-out is given to integrating type ADCs. The royal sum pulses are discriminated at predetermined thresholds and event trigger is generated when there is any four-fold coincidence among six royal sums. Once an event trigger is generated, CAMAC controller initiates the data recording process. TDC start pulse is generated and individual TDC channels are stopped by appropriately delayed signals from delay circuit as mentioned before. So TDC readings are the measure of relative delay in arrival of shower front at various mirrors. Following a trigger ADC gate is generated and pulses from various mirrors are digitized by the ADCs. Finally the CAMAC controller interrupts *linux* based PC which initiates the data recording process. Recorded data are the *latch* information which tells us which telescopes have participated in the trigger, absolute time of the event arrival correct to  $\mu s$  in addition to TDC and ADC's. At present, ADC's and TDC's corresponding to six peripheral mirrors of each telescope are stored.

In addition to the above mentioned event data, monitor data are also recorded periodically. Monitor interrupts are generated at MSPC and fed to each of FSPC's which initiates recording of data comprising of mirror rates and royal sums along with absolute time from RTC. Monitor interrupts are variable but periodic.

#### 4.2 Master Data Acquisition System (MDAS)

MDAS records data relevant to the entire array. There are two types of data recorded corresponding to two types of triggers as in the case of SDAS. Royal sums from all the stations are brought to the control room. Whenever an event trigger is generated at any station, MDAS CAMAC controller is interrupted and the TDC delays, event arrival time from RTC, latch indicating the sectors participating in trigger, no. of events recorded in various stations are read and stored. Following each periodic monitor interrupt, royal sum rates are recorded. Using data recorded by MDAS, data from stations can be collated off-line.

#### 4.3 Software

The software developed for PACT can be classified into four groups.

##### 1. System software consisting of

- a. Data acquisition software which initiates the data recording process following top priority event interrupt. It also records RTC latched by event trigger and starts reading the latched data from various CAMAC modules. The data read are stored in hard disc using double buffer scheme in order to reduce

the system dead time. Checksum word is used at the end of each event data to improve the data reliability. Data acquisition software is divided into several sub-tasks as follows :

- (i) Device drive module (DDM)
- (ii) Device drive control module (DDCM)
- (iii) Data display module (DDSP) and
- (iv) Data server module
- b. Monitoring interrupt servicing routine which latches and reads all the scalers which count the various phototube and royal sum counting rates during the time interval between two consecutive interrupts. Monitoring data are stored in a different file for off-line analysis.

##### 2. Utility software like

- a. software to preset and synchronize the various RTC's,
- b. software to feed counting rate information to CARAMS through serial port. This is accomplished by a System Manager PC in MSPC which receives monitoring data from the SDAS's through LAN and routing them to the PC running CARAMS.
- c. on-line quick-look analysis program to check the data fidelity and other checks.

##### 3. Online monitoring and display routines like

- a. read and display count and chance coincidence rates for all the sectors,
- b. read and display royal sum rates online.

These tasks exploit the *Linux* networking capabilities since all the PC's under *Linux* are networked.

##### 4. Several off-line data handling routines which read and check each and every aspect of the data and produce a test report for each run, produce various types of distributions to ensure the general health of the data.

Software under (1) and (2) are developed in *C* while (3) and (4) are designed under IDL. All the software except CARAMS and ACTOS work under *Linux* while the latter work under DOS.

## 5 Status of PACT

PACT is fully operational since December 2000. All the sub-systems are functioning satisfactorily. Several sources including Crab nebula, Mkn 421, Mkn 501, Geminga and 1ES 1426+428 have been observed and some preliminary results on some of these are presented by Bhat *et al.*, 2001 and Vishwanath *et al.*, 2001.

## References

- Chitnis, V. R. *et al.*, 'Pachmarhi Array of Čerenkov Telescopes and its sensitivity', these proceedings, 2001.
- Bhat, P. N. *et al.*, 'Observations of Mkn 421 using Pachmarhi Array of Čerenkov Telescopes', these proceedings, 2001.
- Gothe, K. S. *et al.*, Indian Journal of Pure & Applied Physics, 38, 269, 2000.
- Vishwanath, P. R. *et al.*, 'VHE  $\gamma$ -rays from the crab nebula from the PACT array', these proceedings, 2001.

This figure "actos.jpeg" is available in "jpeg" format from:

<http://arXiv.org/ps/astro-ph/0109003v1>

This figure "ex-su-col.gif" is available in "gif" format from:

<http://arXiv.org/ps/astro-ph/0109003v1>

This figure "pcm\_array.jpg" is available in "jpg" format from:

<http://arXiv.org/ps/astro-ph/0109003v1>

This figure "sdas2.jpeg" is available in "jpeg" format from:

<http://arXiv.org/ps/astro-ph/0109003v1>